A new system to quantify uncertainties in LEO satellite position determination due to space weather events

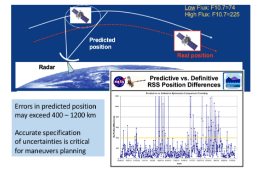
Completed Technology Project (2016 - 2018)

Project Introduction

We propose to develop a new system for quantitative assessment of uncertainties in LEO satellite position caused by storm time changes in space environmental parameters. The system will couple a unique and expanding collection of upper atmosphere models and Sun-to-Earth modeling chains available at the Community Coordinated Modeling Center (CCMC) with orbit determination algorithms utilized by the NASA/GSFC Flight Dynamics facility (FDF) and Conjunction Assessment Risk Analysis (CARA) group. The system will translate uncertainties in predicted atmospheric neutral density into differences between predicted and definitive orbits. This approach will address the lack of contemporary, high-resolution mass density and composition observational data and will utilize available definitive orbits as a ground truth for assessment of atmospheric neutral density modeling capabilities. The proposed effort is a game changing step towards quantitative assessment of state-of-the-art and building much needed NASA/GSFC in-house satellite drag prediction capabilities. The project will require multi-disciplinary collaboration among space environment domain experts, software engineers, and flight dynamics specialists.

Atmospheric drag is one of the major space weather impacts on assets in space at altitudes up to 2000 km. Satellite drag severely impacts many aspects of NASA operations, including precision orbital determination (catalog, collision avoidance, reentry), space debris avoidance, fuel maintenance, lifetime estimates, attitude control system design, and spacecraft design. NASA/GSFC Flight Dynamics facility (FDF) and Conjunction Assessment Risk Analysis (CARA) group are relying on orbit errors provided by the Air Force Command using long-term averages and unknown methodology. Operational drag models are based on empirical models that use global solar and geomagnetic indices as input; however, uncertainties in current and predicted indices can lead to unacceptably large errors in orbit determinations. Most importantly, the uncertainties in orbit prediction during space weather events are not quantified, which makes accurate assessment of storm impact on conjunction events impossible. *There is a clear call-to-action to quantify uncertainties in orbit predictions, to perform analysis aiming to advance understanding of storm impact on satellite drag, and to move towards improved satellite drag predictive capabilities during storm times.*

The CCMC hosts a unique, expanding collection of space environment models and Sun-to-Earth model chains, and leads community-wide efforts to assess space environment predictive capabilities including the ability to specify and forecast space-weather event impacts on atmospheric neutral density. The lack of contemporary, high-resolution mass density and composition observational data is a serious impediment for atmospheric density model-data comparisons and further model improvements. Therefore *we need to implement an alternative metrics and validation approach appropriate for satellite drag applications* that relies on available resources such as precise definitive orbits of LEO satellites. GSFC FDF maintains historical ephemeris



Changes in space environment cause errors in orbit determination. Accurate specification of satellite location uncertainties is critical for maneuver planning.

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records of the definitive orbit solutions for a broad range of altitudes as well as information about satellites orientation along the orbits that is required to evaluate drag coefficients. With this resource, we will use differences between definitive and predicted positions as a metrics for neutral density modeling capabilities and will translate uncertainties in predicted solar and geomagnetic indices and space environment parameters into quantitative uncertainties in orbit determinations.

Space weather events trigger localized energy input from the magnetosphere that causes localized atmospheric density enhancements and strongly modify drag coefficients due to Joule heating and composition change, significantly affecting overpassing orbits. Empirical models driven by global indices typically miss such localized enhancements, while such features are captured by state-of-the-art physics-based models with realistic multi-scale dynamics. Although physics-based models offer a clear path to improved forecasting, they are currently underutilized for orbit propagation tools. We need to couple physics-based models with orbit propagators to: a) quantify the impact of storm-triggered density structures on satellite drag; b) analyze the sensitivity of satellite paths with respect to locations of increased density structures; c) evaluate and the potential of physics-based models to improve storm-time satellite drag modeling.

The primary objective of this effort is to develop a system that will:

1. translate uncertainties in predicted environmental parameters affecting satellite drag into uncertainties in orbit determinations;
2. enable analysis of sensitivities to temporal and spatial variations of neutral density along satellite orbits and estimate uncertainties related to long-term averaging;
3. establish metrics for atmosphere density specifications and forecasts based on deviations of predicted orbits from definitive orbits for different time windows;
4. compare the value of different empirical and physics-based models that predict neutral densities for quantifying storm impacts on satellite drag; establish benchmarks, and enable tracing of improvements in predictive capabilities over time; identify new pathways for reducing uncertainties and enhancing satellite drag prediction capabilities.

Anticipated Benefits

The project will help to define metrics to evaluate current neutral densities predictive capabilities developed under NASA funded projects and to trace progress over time. Defined set of metrics will be tailored to needs of NASA funded missions.

Organizational Responsibility

Responsible Mission Directorate:

Mission Support Directorate (MSD)

Lead Center / Facility:

Goddard Space Flight Center (GSFC)

Responsible Program:

Center Independent Research & Development: GSFC IRAD

Project Management

Program Manager:

Peter M Hughes

Project Manager:

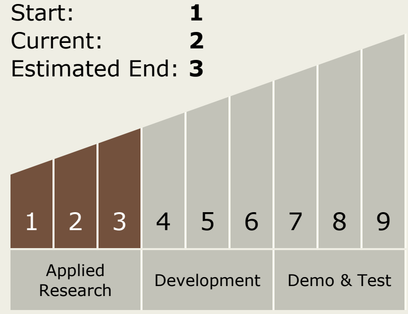
Nikolaos Paschalidis

Principal Investigator:

Maria M Kuznetsova

Technology Maturity (TRL)

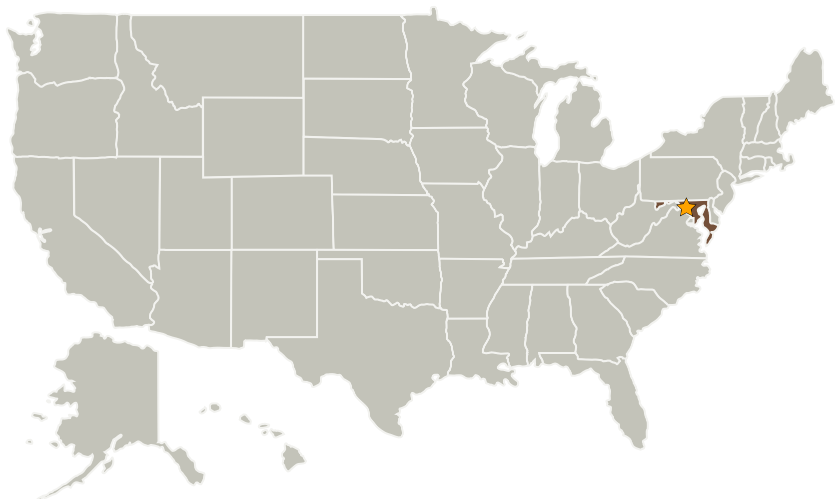
Start: **1**
Current: **2**
Estimated End: **3**



Uncertainty assessment in orbit determination can be implemented for future mission planning.

Accurate orbit determination is of critical importanse to the commercial space industry. Therefore, uncertainty assessment in orbit determination will be beneficial to the commercial space industry.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
★Goddard Space Flight Center(GSFC)	Lead Organization	NASA Center	Greenbelt, Maryland

Primary U.S. Work Locations
Maryland

Technology Areas

Primary:

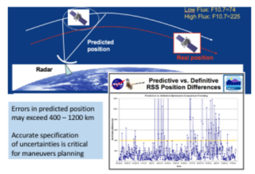
- TX06 Human Health, Life Support, and Habitation Systems
  └ TX06.5 Radiation
    └ TX06.5.4 Space Weather Prediction

Target Destination

Earth

Images

Error in orbit determination due to satellite drag effects
Changes in space environment cased by space weather event impact satellite orbits that results in larger than acceptable differences between expected and actual satellite location. Estimates of these uncertainties is the primary goal of the projects.
(https://techport.nasa.gov/image/26370)



Space Environment impact on satellite orbit
Changes in space environment cause errors in orbit determination. Accurate specification of satellite location uncertainties is critical for maneuver planning.
(https://techport.nasa.gov/image/26371)